Bolus Consistency And Swallowing In Children And Adults

By: Jacki L. Ruark, **Gary H. McCullough**, Rebecca L. Peters, and Christopher A. Moore

Abstract
Research has shown that swallowing in adults is affected by bolus consistency. Little is known, however, regarding the effect of bolus con- sistency on swallowing in children. Electromyo- graphic (EMG) data from typically developing five- and eight-year-old-children and adults were obtained from the following muscles as they swallowed boluses of different consistencies: (1) right upper lip, (2) right lower lip, (3) submental, and (4) laryngeal strap. Signal analyses included calculating EMG onset and offset and average EMG amplitude of muscle activity during swallowing. Findings revealed that by five years of age, children employ adult-like control strategies during swallowing: significant differences in duration and magnitude of muscle activity resulted as a function of bolus consistency. General observations revealed, however, that swallowing in children is characterized by muscle activity that is shorter in duration. Similarities and differences in the biomechanics of swallowing between children and adults are important to consider during clinical evaluations and treatment of children with dysphagia.

Jacki L. Ruark, **Gary H. McCullough**, Rebecca L. Peters, and Christopher A. Moore (2002) "Bolus Consistency And Swallowing In Children And Adults" *Dysphagia* #17 pp.24-33
Version of Record available @ www.springer.com (DOI: 10.1007/s00455-001-0098-0)

Introduction

The clinical evaluation of a child with suspected dysphagia includes presenting various liquid and food items to determine the effect of bolus consistency on swallowing [1]. Identifying consistencies that are safe for swallowing allows clinicians not only to determine the need for diet modification (e.g., eliminating problem consistencies from the child's diet), but also to monitor swallowing skills and establish pertinent treatment goals [2]. One compensatory strategy frequently employed to enhance swallowing in children with dysphagia is to alter the physical characteristics of food substances within a child's diet (e.g., thickening of liquids to improve bolus formation) [3]. It is generally assumed that some consistencies are easier to swallow than others, and swallowing coordination in children is affected by bolus consistency [4]. Although positive clinical outcomes are frequently reported subsequent to consistency modification in children with dysphagia [2], quantitative evidence regarding the effect of bolus consistency on swallowing in children is lacking.

In adults, several studies have focused on the effect of bolus consistency on the coordinative variables of swallowing [5-7]. For example, Dantas and Dodds [5], using concurrent recordings of submental and infrahyoid EMG activity and videofluoroscopy of adults during swallowing, found that boluses of barium paste yield greater duration and amplitude of submental and infrahyoid muscle activity than liquid barium. Additionally, the onset of infrahyoid EMG activity occurs later in the swallow for barium paste (i.e., onset of infrahyoid EMG activity occurs 0.25 s after initiation of submental EMG activity for bari- um paste, 0.18 s after initiation of submental EMG activity for liquid barium).

In a study that used common liquid and food items to determine the effect of bolus consistency on swallowing in adults, Reimers-Neils et al. [7] found that the total duration of muscle activity of adults during swallowing (as measured by the duration of time from the initiation to cessation of submental and infrahyoid EMG activity during swallowing) significantly increased from liquid (e.g., water) to thin paste (e.g., pudding) and from thin paste to thick paste consistencies (e.g., cheese spread). Reimers-Neils and colleagues also found that the magnitude of submental EMG activity significantly increased when the adults swallowed thick versus thin pastes and thin or thick pastes versus liquids. Significant differences were not found, however, when comparing liquids to thin paste. The magnitude of infrahyoid EMG activity was similarly affected by bolus consistency, although the average EMG amplitude of the infrahyoid muscles did not differ significantly when adults swallowed thin versus thick pastes. The outcome of this investigation demonstrated that, although submental and laryngeal EMG activity of adults is affected by bolus consistency, the effect of bolus consistency on muscle activity during swallowing may not follow conventional clinical concepts (e.g., that a liquid bolus requires less magnitude of muscle activity during swallowing than pudding). In conclusion, these investigators recommended that further documentation be obtained regarding the effects of bolus consistency on swallowing in typical individuals. In addition, the authors suggested that liquid and food items used during swallowing evaluations and treatment be standardized.

Empirical investigations regarding the maturation of the swallow have focused primarily on describing the coordination of swallowing with sucking and breathing in infants [e.g., 8,9]. Consequently, there is little understanding of the effects of bolus consistency on swallowing in typically developing children. The notion that a mature swallow is established during early development, e.g., by 15 months of age [10], suggests that swallowing in children and adults is similarly affected by bolus consistency. This assumption also implies that swallowing in children is characterized by similar relationships between submental and infrahyoid EMG activity and movements of various oropharyngeal structures as adults (e.g., infrahyoid EMG activity parallels the arrival of the bolus at the faucial pillars [5]). However, as dramatic alterations in neuromuscular and musculoskeletal systems transpire until at least 11 years of age [11,12], it is difficult to infer from adult studies the effect of bolus consistency on swallowing in children. In fact, there is little quantitative information regarding the ontogeny of swallowing in humans [13]. A better understanding of swallowing in children is necessary to determine when children should develop a more mature swallowing pattern and when the absence of mature patterns should become a concern. The goal of the present investigation was to obtain comprehensive EMG data from children and adults and determine whether children employ adultlike control strategies as they swallow boluses that differ in consistency.

The following anatomcal and physiological factors led to the hypothesis that the average magnitude and duration of muscle activity during swallowing in children differs from adults: (1) the swallowing tract of children is shorter and is composed of muscle fibers that differ in size and histology [14,15] and (2) the central and peripheral nervous systems, including motor neurons, sensory receptors, and their connections, continue to develop into late childhood [11].

Method

Participants

Participants in this investigation included 10 typically developing five-year-old females, 10 typically developing eight-year-old females, and 10 young adult females (mean age = 22 years). These age ranges were selected because children of similar ages in other physiological studies demonstrated coordinative differences in lip and jaw muscle activity when compared with adults [16,17]. Males were excluded to control for potential effects of structure and growth patterns on swallowing activity [18]. Each participant was free of known neural deficits and current upper respiratory infection. Caretaker interviews indicated that all children had normal histories of gross and fine motor development and demonstrated normal progression of feeding skills, such as sucking from a bottle readily at birth and intake of cereal or pureed consistencies by six months of age [19,20]. All adults were undergraduate students in speech-language pathology at the University of Tennessee and reported negative histories of neural pathology, feeding problems, or swallowing difficulties. Prior to the experimental session, each participant's swallow was screened to assure that the participant produced a typical" swallowing pattern [21]. Although there are no reliability and validity measures for the screening procedure, it gave the investigators a noninvasive means to identify any observable, deviant swallowing behaviors (e.g., tongue thrusting, drooling). In addition, an oral mechanism screening was performed using the Oral Speech Mechanism Screening Examination-Revised [22] to determine any abnormalities or deviations of oral musculature.

Procedures

Electrode Placement

Each participant was seated at a table facing one of the investigators. Electrode placement was initiated after experimental procedures were explained and informed consent was obtained. Prior to electrode placement, target areas were lightly scrubbed with alcohol gauze pads, followed by application of an antiperspirant skin electrode preparation (Prep N'Stay, Pharmaceutical Innovations, Inc., Newark, New Jersey). Bipolar surface EMG recordings were made from four target sites: (1) right upper lip (RUL), (2) right lower lip (RLL), (3) submental muscles (SM) targeting the right and left anterior bellies of the digastric, and (4) laryngeal strap muscles (LSM) targeting the right thyrohyoid. Ag/AgCl disk electrodes (In Vivo Metrics, Ukiah, California, 4 mm o.d.), filled with a hypoallergenic electrode cream (Synapse, Med-Tek, Inc., Ukiah, California), were attached to the target areas using adhesive electrode collars. The shape of the collars used to secure the lip electrodes were modified to allow for better placement within the target areas. The lip electrodes were placed 0.5 cm apart, just lateral to the philtrum groove, adjacent to the vermilion, and at least 1 cm from the corner of the mouth. This placement procedure has been found to preclude crosstalk between upper and lower lip EMG recordings and avoid contamination by other more distal muscles [23]. The SM electrodes were located by palpating the main mass of the right and left muscle as the participant opened her mouth. These electrodes were also placed 0.5 cm apart and included the area immediately posterior to the mental symphysis. The LSM electrodes were placed one perpendicular to the other, 0.2 cm above and 0.5 cm lateral to the participant's thyroid prominence. This placement site was initially verified by palpating the main muscle mass as the participant swallowed water. One additional electrode was placed on the participant's forehead to serve as ground. Electrode recordings were made continuously throughout the 45-minute experimental session. EMG signals were differentially amplified using Grass P511 physiologic preamplifiers (frequency response: 30-3000 kHz), filtered to prevent aliasing, and recorded on 1 of 16 channels of an instrumentation frequency-modulated DAT recorder (TEAC RD-200T PCM) for subsequent offiine digitization and analysis. A single audio channel was used to simultaneously record an experimenter's verbal indication that the child swallowed and descriptions of target behaviors (e.g., presence of muscle activity just prior to swallowing). Changes in experimental conditions and preliminary data description were recorded by a second experimenter on a second audio channel. Thus, six channels were recorded online: 4 EMG and 2 audio channels.

Experimental Tasks

After electrode placement, each participant performed five tasks, each task consisting of three trials of swallowing 3 cc of a particular liquid or food consistency, including:

1. liquid — tap water
2. thickened liquid — a mixture of one-part apple juice to one-part applesauce (The Kroger Company, Cincinnati, OH)
3. pudding (Kraft Foods, Inc., Rye Brook, NY)
4. cheese spread (Easy Cheese®, Nabisco Foods, East Hanover, NJ)
5. gummy bear (Favorite Brands International, Lincolnshire, IL) (one gummy bear was presented per trial)

A total of 15 swallows were obtained per participant (5 consistencies x three trials). Bolus volume was held constant across all trials so any changes in swallowing could be attributed to changes in bolus consistency. All liquid and food items were held at room temperature and, except for the gummy bear and cheese spread, were presented to the participant via syringe (the volume of cheese spread was first measured then presented via spoon). These tasks were selected because similar liquid and food items (water, pudding, cheese spread) were presented to adult participants in a previous investigation on swallowing [7]. Two additional reasons for selecting the above liquid and food items as opposed to standardized materials include: (1) these items may be used during a clinical swallow examination in young children and adults (e.g., water, pudding, and thickened apple juice), and (2) the appeal of these items to young participants. After the liquid or food item was placed in the participant's oral cavity, the participant was given the following command: Hold this in your mouth until I tell you to swallow," followed by the command Swallow." The subsequent command to swallow was given when visual inspection of the computer screen indicated that all four EMG records demonstrated little-to-no electrical activity prior to the swallow, and no other unwanted artifacts were present (e.g., movement artifacts). For items that required mastication or some type of oral manipulation prior to a swallow, participants were instructed to move" or chew" the bolus as needed and to raise their hand when ready to swallow. An experimenter verified the occurrence of each initial and subsequent swallows per trial by palpating the participant's contralateral laryngeal strap muscles and verbally stating into the microphone when laryngeal movements occurred.

Data Selection

From each 45-minute taped session, target behaviors were identified and parsed for subsequent digitization and analysis. In the advent that a participant produced more than one swallow per trial, the initial swallow was chosen for analyses. The four EMG channels, as well as the first audio channel (containing experimenter No. 1's verification of the swallow event) were digitized (1000 samples/s/channel). The first audio channel was digitized for data identification only (in the advent that the target data were surrounded by nontargeted EMG activity, such as oral movements prior to the swallow). Two investigators were involved in data selection and digitization, and a 97.9 mean percent agreement for inter-rater reliability was obtained.

Signal Processing and Analysis of EMG Signals

EMG activity of the four muscles was analyzed using algorithms custom designed for Matlab (v0.4.2c; The Mathworks, Inc., Anaheim, California, 1993), a commercially available signal processing package. The analyses of the four EMG records included the calculations of (1) EMG onset and offset and (2) average EMG amplitude. These analyses have been used empirically to quantify the coordinative variables of submental and laryngeal strap muscle activity during swallowing and various muscle systems during speech and nonspeech activities [7,24,25].

Duration Analysis

The duration analysis followed the protocol established by Green et al. [24] which encompassed a combination of both automatic and computer-assisted identification of EMG onset and offset. Initially, each EMG record was full-wave rectified and digitally filtered (8-pole Butterworth, lowpass cutoff = 30 Hz). Next, a computer-generated algorithm determined the lowest level of activity for each EMG record and drew a line 1 SD above this level (i.e., across the floor of the corresponding record). These threshold lines were then used as references to determine the onset and offset of EMG activity per record (decreasing the possibility of measurement bias and error). The final step of selecting EMG onset and offset involved an investigator placing two markers on the SD line where each EMG record began to exceed the threshold line (one mark for onset, one mark for offset). Figure 1 is an example of the signal-processing stages where EMG records were first (A) rectified, then (B) low-passed filtered. These EMG records are from an eight-year-old child as she swallowed 3 cc of water. Figure 2 illustrates how the SD threshold line (dashed line on the first filtered EMG record)

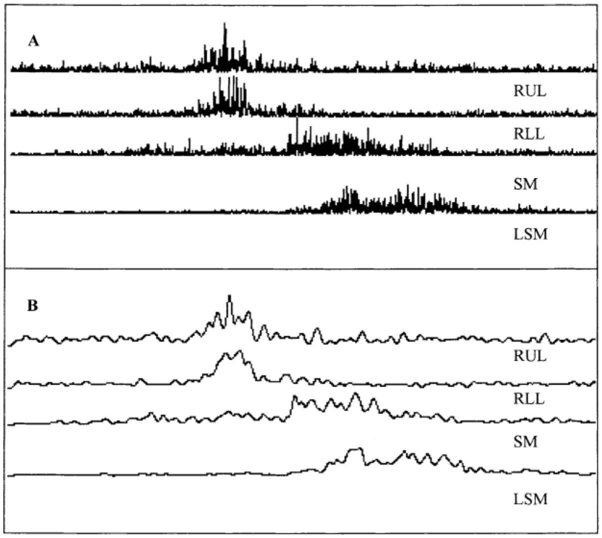

Fig. 1. Example of (A) rectified and (B) rectified and fi EMG signals of the following muscles from an eight-year-old child as she swallowed 3 cc of water: right upper lip (RUL), right lower lip (RLL), submental (SM), and laryngeal strap muscles (LSM).

was drawn via computer to assist in the selection of onset and offset of right-upper-lip EMG activity. Information regarding the selected time periods of onset and offset of the four EMG records were automatically stored in a computer file designated for a particular participant and consistency.

Average EMG Amplitude Analysis

A custom-designed algorithm was used to calculate the average EMG amplitude of muscle activity of the targeted muscles during swallowing. Initially, the raw EMG records were demeaned, full-wave rectified, and low-pass filtered (8-pole Butterworth filter; lowpass cutoff = 30 Hz). A cursor was then used to mark two areas that signified the beginning and end of each EMG burst (as detected previously by the analysis of EMG onset and offset). A computer-generated algorithm subsequently calculated the cumulative sum of the area between the two marked portions and divided this value by the duration of the marked portion (in milliseconds).

Reliability

Two experimenters performed the duration and average EMG amplitude analyses on three complete data sets (one data set chosen randomly from each age group). Interjudge reliability was assessed by comparing scores obtained for each swallowing trial for each of the five tasks (45 swallowing trials per participant). The following percent agreement scores were obtained for all data combined; 92.8 and 89.4 for duration and average EMG amplitude analyses, respectively.

Statistical Analyses

There were several instances in which child participants refused to participate in specific experimental trials. As a result, data were obtained for only 99.94% of the conditions. Four participants (2 five year olds and 2 eight year olds) refused the thickened liquid consistency, and 1 participant (eight year old) refused the thickened liquid, pudding, and cheese spread consistencies. In addition, 1 five year old refused one trial of the cheese spread consistency and two trials of the gummy bear consistency. Thus, out of a total of 1800 possible data points (30 participants x 4 muscles x 5 consistencies x 3 swallow trials), 0.06% were missing values. To complete the data set and avoid risk of under-representation of data from child participants, missing values were imputed before further statistical analyses were performed.

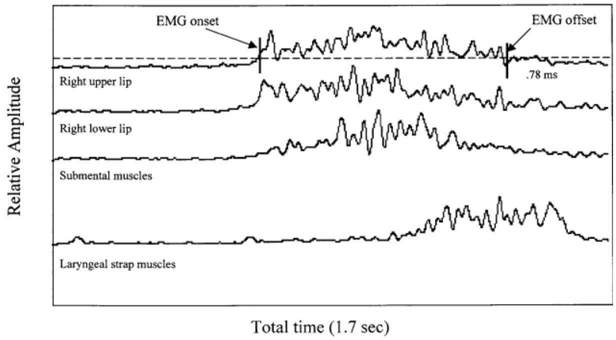

Fig. 2. Example of selection process for onset and off et of right-upper-lip EMG signal. Dashed line represents those points that are 1 SD above the signal floor.

Results

Duration of Muscle Activity

A three-way repeated-measures analysis of variance (ANOVA), which included consistency and muscle as within-subjects factors and age as the between-subjects factor, was conducted on average duration of muscle activity. In order to correct for lack of sphericity in the covariance matrices, the Huynh-Feldt procedure was used to adjust degrees of freedom. Tests of simple effects were performed to explore interactions and were followed by *post hoc* analyses of differences (Tukey HSD). Main effects, interactions, and simple-effect followup tests were considered significant at the alpha level of 0.05. Statistical treatment and analyses were performed using SPSS software [26,27].

Findings of the ANOVA revealed that there was no significant main effect for age but a significant muscle main effect [$F_{(1.46,\ 39.59)} = 7.91$, $p = 0.003$] and a significant interaction between muscle and consistency [$F_{(5.18,\ 139.96)} = 3.30$, $p = 0.007$] (see Table 1). To further explore the nature of the interaction, simple-effect followup tests were performed to compare bolus consistency separately for each muscle. Results of these analyses indicated that the average duration of submental muscle activity

Table 1. Results of the three-way ANOVA for repeated measures for the effects of consistency, muscle, and age on average duration of muscle activity

Effect	F	df	Error df	Significance
Consistency	2.03	3.91	105.70	0.01
Consistency x age	0.46	7.83	105.70	0.87
Muscle	7.91	1.46	39.59	0.003
Muscle x age	1.99	2.93	39.59	0.13
Consistency x muscle	3.30	5.18	139.96	0.007
Consistency x muscle x age	0.93	10.36	139.96	0.51

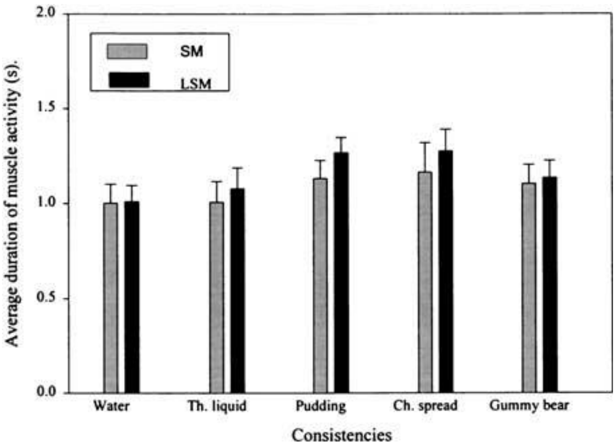

Fig. 3. Average duration of submental (SM) and laryngeal strap muscle (LSM) activity in children across bolus consistency.

[$F_{(3.7,\ 106.17)} = 3.96$, $p = 0.006$] and laryngeal strap muscle activity [$F_{(3.79,109.99)} = 6.49$, $p = 0.0001$] were significantly affected by bolus consistency. Subsequent *post hoc* testing revealed that significant increases in average duration of submental muscle activity occurred when participants swallowed cheese spread consistency vs. water ($p = 0.009$). Significant increases in the average duration of laryngeal strap muscle activity occurred when participants swallowed pudding vs. water ($p = 0.017$), cheese spread vs. water ($p = 0.003$), and cheese spread vs. the gummy bear consistency ($p = 0.04$).

Figures 3 and 4 present the average duration of submental and laryngeal strap muscle activity in children and adults for each of the five swallowing tasks. Since there were no significant differences in duration of lip muscle activity across tasks, bars representing data obtained from these muscles are excluded from the figures; findings from the five- and eight-year-old children were combined in Figure 3. A general observation of group means shows that the average duration of SM and LSM activity in children and LSM activity in adults followed a similar trend: systematic increases in the duration of muscle activity occurred from liquid to cheese spread consistencies.

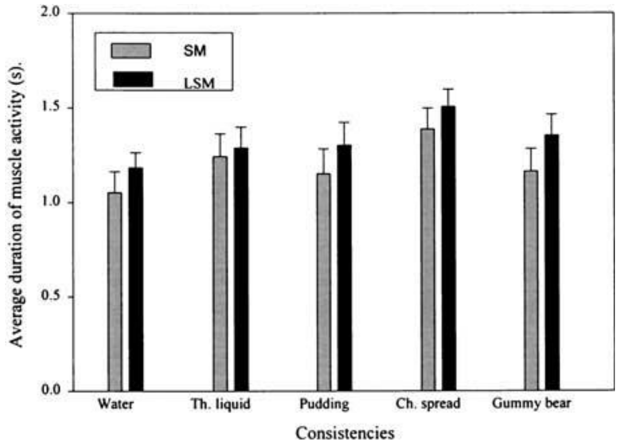

Fig. 4. Average duration of submental (SM) and laryngeal strap muscle (LSM) activity in adults across bolus consistency.

Table 2. Results of the three-way ANOVA for repeated measures for the effects of consistency, muscle, and age on average EMG amplitude of muscle activity

Effect	F	df	Error df	Significance
Consistency	6.14	4.000	24.000	0.001
Consistency x age	1.18	8.000	50.000	0.328
Muscle	2.941	3.000	25.000	0.053
Muscle x age	1.216	6.000	52.000	0.313
Consistency x muscle	1.378	12.000	16.000	0.270
Consistency x muscle x age	1.507	24.000	34.000	0.134

In addition, the average duration of muscle activity in children was typically shorter than adults for all consistencies except pudding.

Average EMG Amplitude of Muscle Activity

To allow statistical analyses of the average EMG amplitude data, each EMG amplitude value was normalized within each muscle and participant. This procedure included converting the mean EMG amplitude value obtained during the water-swallowing task to 100% (deemed the baseline value). The EMG amplitude values for the remaining consistencies were then transformed to a percentage of baseline. The normalization procedure was performed to compare the percent change" in mean EMG amplitude values of individual muscles as a function of bolus consistency.

A multivariate ANOVA with a repeated measures design was performed to determine the effect of bolus consistency on group mean percent change in EMG amplitude values from baseline of individual muscles. This analysis indicated a significant main effect for bolus consistency [$F_{(4,24)} = 5.15$,

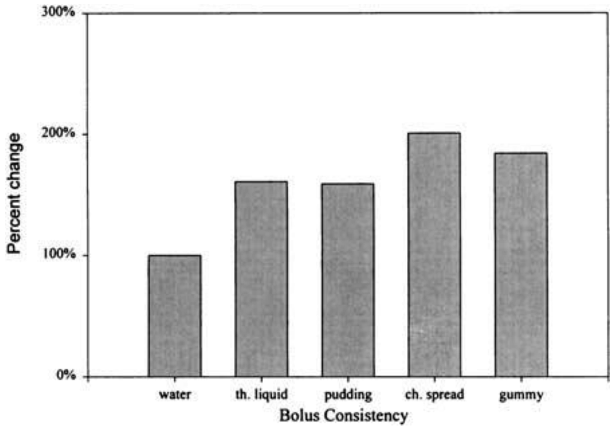

Fig. 5. The eff ct of bolus consistency on percent change in EMG amplitude of muscle activity during swallowing combined across muscles and groups.

$p = 0.004$] only; no other significant effects were indicated. Thus, regardless of muscle or age, the average EMG amplitude of muscle activity is significantly affected by bolus consistency. Subsequent *post hoc* testing revealed that swallowing cheese spread consistency elicited significantly greater EMG amplitude of muscle activity than water ($p = 0.001$), thickened liquid ($p = 0.010$), and pudding consistencies ($p = 0.05$). Gummy bear consistency elicited significantly greater EMG amplitude of muscle activity than water ($p = 0.007$). Figure 5 shows the percent change in average EMG amplitude of muscle activity from baseline (water swallows) for each bolus consistency combined across muscles and groups. General inspection of this figure reveals that the greatest magnitude of muscle activity occurred during cheese spread swallows; the lowest magnitude of muscle activity occurred during water swallows.

Discussion

The present results indicate that by five years of age, children employ adultlike swallowing strategies with regard to bolus consistency. The magnitude and duration of upper and lower lip, submental, and laryngeal strap muscle activity in five- and eight-year old children and adults is similarly affected by bolus consistency. This finding supports previous notions that mature swallowing is established during early development. Although statistically nonsignificant, muscle activity in children is overall shorter in duration than adults. Similarities and differences in the biomechanics of swallowing in children and adults are important to consider during clinical evaluations and treatment of childhood dysphagia.

Bolus Consistency and Duration of Submental and Laryngeal Strap Muscle Activity in Children and Adults

The average duration of submental and laryngeal strap muscle activity in children and adults was significantly affected by bolus consistency. In addition, increases in the average duration of submental and laryngeal strap muscle activity in children and adults appear to be systematic as they swallow boluses that are perceived to increase systematically in consistency (i.e., from water, to thickened liquid, to cheese spread consistency). Although this finding is not statistically significant, it is similar to findings of other EMG investigations of swallowing in adults [5,7]. For example, Reimers-Neils et al. [7] found that the total duration of submental and laryngeal strap muscle activity of adults increased across three consistency categories (i.e., water, pudding, and cheese spread). Similarly, Dantas et al. [5] found that the average duration of submental and laryngeal strap muscle activity significantly increased when adults swallowed liquid barium vs. barium paste. Caution is warranted, however, when comparing across studies as methodological differences limit direct comparisons (e.g., differences in the selection of EMG onset/offset). These studies, however, support findings of the present investigation that the duration of submental and laryngeal strap muscle activity in humans is affected by bolus consistency.

Another finding of the present investigation was the diverse effect of bolus consistency on the average duration of submental muscle activity compared with laryngeal strap muscle activity. In the present investigation, significant differences in the average duration of muscle activity during swallowing depended on the observed muscle and consistency swallowed. The average duration of laryngeal strap muscle activity was significantly affected by various consistencies. In contrast, significant differences in the duration of submental muscle activity were observed only when participants swallowed cheese spread vs. water. Unlike previous investigations, this investigation examined the effect of a greater number of consistency categories on the duration of oropharyngeal muscle activity during swallowing in children and adults (e.g., thickened liquid vs. water, pudding, and cheese spread consistencies). The finding that only the thickest paste consistency (cheese spread) compared with water significantly affected the duration of submental muscle activity may have important clinical implications. Prior to swallowing, food particles are reduced to an appropriate size and consistency by adding saliva to the bolus and by mastication or oral manipulation. Findings of this investigation suggest that each consistency, except for cheese spread, may be altered to a consistency level that is similar to water prior to swallowing. The rheological characteristics of cheese spread may result in the need for submental muscles to be activated for longer periods of time in order to clear this consistency from the oral cavity.

The finding that bolus consistency yields diverse effects on the average duration of muscle activity may also implicate the different sensory systems involved in swallowing. For example, laryngeal epithelia is more richly innervated with sensory receptors (i.e., free nerve endings) than oral epithelia, and mechanoreceptors within oral, pharyngeal, and laryngeal regions are stimulus-specific (e.g., light touch is the optimal mechanical stimulus that elicits a swallow in the posterior pharynx; mechanical pressure does not elicit swallowing from within the oral cavity) [28-30]. In addition, mechanoreceptors within the oral and pharyngeal regions synapse on different substrates within the brain stem (i.e., receptors within oral mucosae synapse in the pons; those in the posterior pharynx synapse in the nucleus tractus solitarius of the medulla). Stimulus-specific responses from the oral and pharyngeal cavities may result in specific modifications in the duration of muscle activity during swallowing as a response to bolus consistency. Although these findings indicate specific bolus consistency effects on average duration of submental and laryngeal strap muscle activity during swallowing, one cannot rule out the possibility that these effects may be due to methodological artifacts. For example, the duration of submental muscle activity was found to be significantly longer when participants swallowed cheese spread consistency in comparison to water. In the majority of participants, cheese spread consistency elicited some type of oral manipulation. Even though participants were instructed to quiet all muscle activity prior to swallowing, some may have manipulated the cheese spread bolus after the command to swallow was given (e.g., to further masticate the bolus or to get the bolus in an optimum position before swallowing). The duration of muscle activity during swallowing may be affected by such manipulations [31].

Diferences in Duration of Muscle Activity During Swallowing in Children and Adults

General observations indicate that children produce muscle activity that is shorter in duration during swallowing. This finding is most likely due to anatomical and/or neuromuscular differences between children and adults. For example, children possess shorter swallowing tracts which means less time is needed for a bolus to travel through the oropharyngeal cavity. This notion is supported by various studies that have measured bolus transit time in typically developing infants and children during swallowing [32,33]. In addition, the developing and mature swallowing tracts of humans are composed of muscle fibers that differ in size and histological composition. In one physiologic investigation, Vignon et al. [15] found that the mylohyoid of infants and children (up to 13 years of age) is largely composed of Type II fibers (Type I fibers are more prominent in adults), and these, as well as other fiber types, were smaller in diameter than those of adults. Several physiologic investigations support the notion that fiber size and histologic makeup of muscles directly influence the coordination of oromotor patterns [34,35].

Bolus Consistency and Amplitude of Muscle Activity in Children and Adults

In the current investigation, the following consistencies yielded significantly greater magnitude of muscle activity during swallowing in children and adults: cheese spread consistency versus water, thickened liquid, and pudding consistencies; gummy bear consistency yielded significantly greater magnitude of muscle activity than water. Although some liquid and food items are perceived to be of greater consistency than others (e.g., pudding versus water), these items did not significantly increase the magnitude of muscle activity produced during swallowing.

Findings from the present investigation support those of Reimers-Neils et al. [7] who found that the average EMG amplitude of submental muscle activity significantly increases as adults swallow thick paste consistencies (i.e., cheese spread or peanut butter) versus thin liquids (i.e., juice or water) or thin paste consistencies (i.e., pudding or applesauce). Similarly, each investigation found that a significant increase in the magnitude of submental muscle activity did not occur when participants swallowed thin paste (i.e., pudding) versus liquid consistencies. These findings suggest that in regard to submental muscle activity, comparable liquid and food items (e.g., manufactured pudding used in both investigations) may yield similar changes in the magnitude of muscle activity during swallowing. This hypothesis, however, may pertain only to submental muscles, as Reimers-Neils and colleagues found that the average EMG amplitude of laryngeal strap muscles significantly increases only as adults swallow thick paste consistencies vs. liquid. The magnitude of laryngeal strap muscle activity in the present investigation, however, was significantly affected by various consistencies. Methodological differences between these two investigations may account for discrepancies among findings. In all, results of both investigations suggest that the subjective classification of liquid and food substances to particular consistency categories may result in the selection of inappropriate diet changes for children and adults with dysphagia [7]. For example, a child who exhibits a decrease in submental muscle activity during swallowing may be given a diet that consists of thickened liquids rather than pudding-like consistencies when, in fact, both consistencies require a similar magnitude, or effort, of submental muscle activity during swallowing.

Although the percent change in average EMG amplitude of muscle activity during swallowing did not significantly differ between children and adults, the average magnitude of lower-lip and laryngeal strap muscle activity in children was greater than adults. This finding may reflect distinct biomechanical characteristics. The greater magnitude of muscle activity exhibited in children during swallowing may result from structural differences between prepubescent females and young adult females, and possibly differences in underlying control mechanisms. Facial soft-tissue size and shape is affected by age and sex [e.g., 36]. These structural differences may affect how a bolus is cleared from the oropharyngeal cavity. For example, greater magnitude of lower-lip muscle activity during swallowing in children may enhance the tongue's ability to propel a bolus posteriorly during the initial part of the swallow (e.g., to help clear the bolus from the anterior sulcus). Previous investigations support the possibility that, during development, sensory receptors and peripheral nerve fibers of orofacial and pharyngeal muscles of children undergo significant anatomical (e.g., changes in size and shape of mechanoreceptors) and physiological changes [37]. For example, the facial nerve and peripheral fibers are not fully myelinated until after four years of age [38]. As mature swallowing patterns can emerge only after the development of essential central and peripheral pathways, it is possible that children obtain more adultlike swallowing strategies as mechanoreceptors and their connections to other neural entities develop. In support of this notion, Bosma [13] states that neurophysiological development allows the child to acquire competence in the evaluation of the physical character of food," and this ability is enhanced when sensory input pertinent to feeding is extended. into the midbrain, cerebellum, thalamus, and ... the cerebral cortex." One can not rule out the possibility, however, that the greater magnitude of muscle activity produced by children was a result of how they manipulated a bolus within the oral cavity before swallowing. Although each participant was encouraged to chew or manipulate a bolus as needed prior to swallowing, some may have swallowed a bolus before it was reduced to an appropriate size or texture. This possibility may have affected the magnitude of muscle activity produced during the swallow.

Clinical Implications

The liquid and food items used in this investigation were selected for two specific reasons: (1) these items represented several consistencies that are commonly included in the evaluation and treatment of children and adults with dysphagia, for example, liquid, thickened liquid, thin paste (pudding), and thick paste (cheese spread) consistencies, and (2) these items were more acceptable to children. One explanation as to why some consistencies yielded similar magnitude or duration of muscle activity during swallowing (e.g., average duration of submental muscle activity was similar for liquid and pudding consistencies) is that these particular substances may share similar physical properties [39]. For example, pudding contains both liquid and solid characteristics and may elicit similar responses in duration of muscle activity to both thickened liquid or cheese spread consistencies. Similarly, the findings of the effect of the gummy" consistency on magnitude or duration of muscle activity during swallowing are difficult to interpret as this type of substance is highly elastic and contains both liquid and solid characteristics. One particular finding of this investigation suggests that, in regard to submental muscles, comparable food items (e.g., two types of pudding) may yield similar effects on magnitude of muscle activity during swallowing. However, food items that appear to be similar in consistency (e.g., pudding vs. applesauce) have been found to elicit very different oromotor responses from typically developing children as well as from children with oromotor disorders [40]. In fact, certain food textures and consistencies, such as solid foods, have been found to elicit more advanced oromotor patterns in younger children than consistencies that are perceived to be easier for children to orally manipulate and swallow [41].

Findings of this investigation suggest that in relation to the effect of bolus consistency on the magnitude and duration of oropharyngeal muscle activity during swallowing, guidelines used to evaluate and treat the adult swallow require little, if any, modification to be used successfully with children five years old or older. This study, however, investigated only some of the physiological elements of swallowing in children. Future studies are needed to determine how the biomechanics of other physiological systems in children during swallowing may differ from adults (e.g., tongue functioning, UES control) and determine the effects of other bolus variables, such as bolus size and temperature. In regard to diagnosing and treating dysphagia in the pediatric population, it is essential that future research focus on obtaining normative data from younger children and the infant population.

Summary

Historically, researchers have proposed that mature swallowing skills are obtained early in development [42]. Findings from the present investigation indicate that swallowing activity, in relation to the magnitude and duration of oropharyngeal muscle activity and bolus consistency, is well established by five years of age. In younger children, swallowing, like other developing oromotor reflexes and centrally patterned behaviors (e.g., chewing), may change throughout the course of early development [24,43]. Future investigations are needed to elucidate the ontogeny of swallowing control and to define typical responses of the developing swallowing system to other bolus variables (e.g., bolus size and temperature).

Acknowledgments. The authors wish to acknowledge the efforts in support of this investigation by Dr. Jordan Green, University of Wisconsin, Madison, and Khuloud Alhendi, M.S., University of Tennessee, for assistance in computer programming.

References

1. Sheppard JJ: Clinical evaluation and treatment. In: Rosenthal SR, Sheppard JJ, Lotze M (eds.): *Dysphagia and the Child With Developmental Disabilities* San Diego, CA: Singular Publishing Group, Inc., 1995, pp 37-75
2. Kramer SS, Eicher PM: The evaluation of pediatric feeding abnormalities. *Dysphagia 8:*215-224, 1993
3. Jolley SG, McClelland KK, Mosesso-Rousseau M: Pharyngeal and swallowing disorders in infants. *Semin Pediatr Surg 4(3):*157-165, 1995
4. Camp KM, Kalscheur MC: Nutritional approach to diagnosis and management of pediatric feeding and swallowing disorders. In: Tuchman DN, Walter RS (eds.): *Disorders of Feeding and Swallowing in Infants and Children.* San Diego CA: Singular Publishing Group, Inc., 1994, pp 153-185
5. Dantas RO, Kern MK, Massey BT, Dodds WJ, Kahrilas PJ, Brasseur JG, Cook IJ, Lang I: Effect of swallowed bolus variables on oral and pharyngeal phases of swallowing. *Am J Physiol 258:*G675-G681, 1990
6. Dantas RO, Dodds WJ: Effect of bolus volume and consistency on swallow-induced submental and infrahyoid electromyographic activity. *Braz J Med Biol Res 23:*37-44, 1990
7. Reimers-Neils L, Logemann J, Larson C: Viscosity effects on EMG activity in normal swallow. *Dysphagia 9:*101-106, 1994
8. Bamford O, Taciak V, Gewolb IH: The relationship between rhythmic swallowing and breathing during suckle feeding in term neonates. *Pediatr Res 31(6):*619-624, 1992
9. Bu'Lock F, Woolridge MW, Baum JD: Development of coordination of sucking, swallowing, and breathing: Ultrasound study of term and preterm infants. *Dev Med Child Neuro 32:*669-678, 1990
10. Moyers R: Postnatal development of the orofacial musculature. *ASHA Rep 6:*38-47, 1971
11. Bawa P: Neural development in children: A neurophysiological study. *Electroencephalogr Clin Neurophysiol 52:*249-256, 1981
12. Kent RD: Anatomical and neuromuscular maturation of the speech mechanism: evidence from acoustic studies. *J Speech Hear Res 19:*421-442, 1976
13. Bosma JF: Development of feeding. *Clin Nutr 55:*210-218, 1986
14. Kent RD, Vorperian HK: Development of the Craniofacial-Oral-Laryngeal Anatomy--A Review. San Diego, CA: Singular Publishing Group, Inc., 1995
15. Vignon C, Pellissier JF, Serratrice G: Further histochemical studies on masticatory muscles. *J Neurol Sci 45:*157-176, 1980
16. Smith BL, McClean-Muse A: Articulatory movement characteristics of labial consonant productions by children and adults. *J Acoust Soc Am 80(5)*:132l-l327, 1986
17. Ruark JL, Peters RL: Lip muscle activity in younger and older children during speech and nonspeech tasks. Conference on Speech Motor Control, Tucson, Az, 1998
18. Kahane JC: Growth of the human prepubertal and pubertal larynx. *J Speech Hear Res 25:*446-455, 1982
19. Arvedson JC, Lefton-Greif MA: Anatomy, physiology, and development of feeding. *Semin Speech Lang. 17(4):*261-269, 1996
20. Stevenson RD, Allaire JH: The development of normal feeding and swallowing. *Pediatr Clin North Am 38(6):*1439-1453, 1991
21. Logemann JA: *Evaluation and Treatment of Swallowing Disorders,* 2nd ed. Austin, TX: Pro-Ed, 1998
22. St. Louis KO, Ruscello DM: *Oral Speech Mechanism Screening Examination-Revised.* Austin, TX: Pro-Ed, 1987
23. Ruark JL, Moore CA: Coordination of lip muscle activity by 2 year old children during speech and nonspeech tasks. *J Speech Lang Hear Res 40:*1373-1385, 1997
24. Green JR, Moore CA, Ruark JL, Rodda PR, Morvee WT, VanWitzenburg MJ: Development of chewing in children from 12 to 48 months: Longitudinal study of EMG patterns. *J Neurophysiol 77:*2704-2716, 1997
25. Moore CA, Ruark JL: Does speech emerge from earlier appearing oral motor behaviors? *J Speech Hear Res 39(6):*1034-1047, 1996
26. SPSS Missing Values Analysis 7.5, SPSS Inc., Chicago IL, 1997

27. SPSS Advanced Models 10.0, SPSS Inc., Chicago IL, 1999
28. Dubner R, Sessle BJ, Storey AT: *The Neural Basis of Oral and Facial Function.* New York: Plenum Press, 1978
29. Miller AJ: Neurophysiological basis of swallowing. *Dysphagia 1:*91-100, 1986
30. Pommerenke WT: A study of the sensory areas eliciting a swallowing reflex. *Am J Physiol 84:*36-41, 1928
31. Perlman AL, Palmer PM, McCulloch TM, Vandaele DJ: Electromyographic activity from human laryngeal, pharyngeal, and submental muscles during swallowing. *J Appl Physiol 86(5)*:1663-1669, 1999
32. Newman LA, Cleveland RH, Blickman JG, Hillman RE, Jaramillo D: Videofluoroscopic analysis of the infant swallow. *Invest Radiol 26*:870-873, 1991
33. Cassas MJ, MacPherson KA, Kenny DJ: Durational aspects of oral swallow in neurologically normal children and children with cerebral palsy: An ultrasound investigation. *Dysphagia 10:*155-159, 1995
34. Herring SW, Wineski LE: Development of the masseter muscle and oral behaviors in the pig. *J Exp Zool 237:*191-207, 1986
35. Lakars TC, Herring SW: Ontogeny of oral function in hamsters. *J Morphol 165:*237-254, 1980
36. Ferraruo VF, Sforza C: Size and shape of soft tissue facial profile: effects of age, gender, and skeletal class. *Cleft Palate Craniofac J 34(6)*:498-504, 1997
37. Darian-Smith I: The trigeminal system. In: Iggo A (ed.): *Handbook of Sensory Physiology II: Somatosensory System.* New York: Springer Verlag pp 271-314,1973
38. May M: *The Facial Nerve.* New York: Thieme Inc., 1986
39. Coster ST, Schwarz BS, Schwarz WH: Rheology and the swallow-safe bolus. *Dysphagia 1:*113-118, 1987
40. Tcheremenska AR, Gisel EG: Use of substitute food textures for standard eating assessment in children with cerebral palsy and children without disabilities. *Am J Occup Ther 48(7):* 626-632, 1994
41. Gisel EG: Chewing cycles in 2- to 8-year-old normal children: A developmental profile. *Am J Occup ther 42(l):*40-46, 1988
42. Moyers R: *Handbook of Orthodontics for the Student and General Practitioner, 2nd ed*. Chicago, IL: Year Book Medical Publishers, Inc., 1958
43. Smith A, Weber CM, Newton J, Denny M: Developmental and age-related changes in reflexes of the human jaw-closing system. *Electroencephalogr Clin Neurophysiol 81:*118-128, 1991